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Atmospheric forcing from the Naval Operational Global Atmospheric Prediction System has been used to drive the U.S. Navy's operational ice models, the Polar Ice Prediction System and the Regional Polar Ice Prediction System - Barents. Unlike many ocean circulation models which depend mainly on wind forcing, ice models are dependent on winds as well as atmospheric heating/cooling (fluxes, air temperatures and solar radiation). Comparisons of the ice model results with observations have shown that the model derived fields are highly sensitive to the atmospheric forcing. An excessively warm atmosphere can cause huge "ice melting" events while an atmosphere which is too cool can cause ice to grow where none has been observed. Wind forcing also plays a major role in the ice model results. Over the short periods of time used in a forecast, winds are dominant in determining ice drift. If the wind is inaccurate, modeled ice drifts are shown to reflect these inaccuracies. The resolution of the atmospheric models are often of the order of hundreds of kilometers, while the ice model's resolution is generally less than 100 km. Mesoscale features are often lost in the coarse resolution of the atmospheric forcing and are therefore

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The Results of Test Cases Examining the Effects of Atmospheric Forcing in Limited Area Ice Models.

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ABSTRACT
Atmospheric forcing from the Naval Operational Global Atmospheric Prediction System has been used to drive the U.S. Navy's operational ice models, the Polar Ice Prediction System and the Regional Polar Ice Prediction System - Barents. Unlike many ocean circulation models which depend mainly on wind forcing, ice models are dependent on winds as well as atmospheric heating/cooling (fluxes, air temperatures and solar radiation). Comparisons of the ice model results with observations have shown that the model derived fields are highly sensitive to the atmospheric forcing. An excessively warm atmosphere can cause huge "ice melting" events while an atmosphere which is too cool can cause ice to grow where none has been observed. Wind forcing also plays a major role in the ice model results. Over the short periods of time used in a forecast, winds are dominant in determining ice drift. If the wind is inaccurate, modeled ice drifts are shown to reflect these inaccuracies. The resolution of the atmospheric models are often of the order of hundreds of kilometers, while the ice model's resolution is generally less than 100 km. Mesoscale features are often lost in the coarse resolution of the atmospheric forcing and are therefore missing from the ice model forecasts. Spectral models, which are presently replacing the existing atmospheric models at the Fleet Numerical Oceanography Center, should provide better forcing for the Arctic. In addition, the resolution of these models will soon be doubled and provide more detailed forcing for the ice models.

1. INTRODUCTION

Sea ice models require accurate forcing fields at both top and bottom interfaces of the ice in order to determine the movement and growth or decay of ice. A number of climatological studies have used monthly mean climatological atmospheric and oceanic forcing resulting in a reasonable ice field. Shorter term ice forecasting such as that done at the Fleet Numerical Oceanography Center (FNOC) by the Polar Ice Prediction System (PIPS) (Preller and Posey, 1989) requires accurate daily forcing. PIPS is used to make a 120 hour forecast of ice drift, ice thickness and ice concentration each day. This paper will focus only on the important effect of atmospheric forcing on PIPS. In all cases presented here, monthly mean geostrophic ocean currents and ocean heat fluxes from the Hibler and Bryan (1987) coupled ice-ocean model are used for the ocean forcing.

The Hibler ice model (Hibler, 1979; 1980), used as the basis for PIPS, requires the following atmospheric forcing fields to drive the model:

surface pressure fields used to defined geostrophic winds and used in conjunction with surface vapor pressure to define the specific humidity at the ice surface, surface air temperatures, incoming solar radiation (short wave) and long wave radiation. The atmospheric forcing fields used to drive PIPS are derived from the Naval Operational Global Atmospheric Prediction System (NOGAPS). Test data sets composed of NOGAPS analysis fields from 1983 and 1986 have been used in this study.

WIND FORCING

Wind stress along with ocean current stress are major components in determining ice drift in the model. Over short periods of time, such as that of a forecast (5 days), wind stress plays the dominant role. In order for PIPS to be declared a U.S. Navy operational product, it had to be proven that PIPS provided better forecasts than the existing operational model. The existing model was an ice drift model based on the free drift relationship defined by Thorndike and Colony (1982). One would expect that PIPS, which includes the effect of internal ice stress, would give more accurate ice drift. An initial qualitative comparison showed the PIPS ice drift to be in very good agreement with the wind forcing. When PIPS and the free drift model were compared to each other and to arctic drifting buoy data, it was found that on the average, PIPS ice drift was almost twice as large as the buoy drift. Free drift results were in much better agreement with the buoy data. Closer examination revealed that these two models were using different wind forcing. The free drift model used geostrophic winds derived from NOGAPS surface pressure fields, while PIPS used FNOC marine boundary layer winds representing surface wind fields. A statistical comparison of PIPS driven by the marine winds and PIPS driven by NOGAPS geostrophic winds to buoy data for 1983 showed that geostrophic wind forcing gave far better results (Preller and Posey, 1989). Results using surface wind forcing showed good comparison only when the drag coefficient was drastically reduced from the observed value of 0.0027 to 0.0001. It was determined that the marine winds were unrealistic and that PIPS driven by geostrophic winds provided better results than the free drift approximation. The new version of PIPS, driven by geostrophic winds, was then declared an operational product.

ATMOSPHERIC HEATING AND COOLING

PIPS is presently monitored and verified against arctic buoy data and against an ice concentration analysis provided by the Naval Polar Oceanography Center (NPOC), at the Naval Oceanographic and Atmospheric Laboratory (NOARL) on a weekly basis. While monitoring PIPS over the past three years, a number of trends in the ice cover have surfaced. During certain years, too much ice grows in the Barents Sea from mid December to mid January and the ice often is too thin in the central Arctic in summer. NOGAPS surface air temperatures as well as long and short wave radiation from the year 1986 were examined to determine what effect might have had on these trends.

A qualitative examination of the net long and short wave radiation was made. Short wave radiation seemed quite realistic with the duration of this solar radiation increasing in the arctic summer. Examination of the long wave radiation used by the model revealed an error existing in PIPS. The convention for direction in the long and short wave radiation fields, unbeknownst to the authors, were opposite. The convention used in PIPS was based on the short wave radiation. The normal cooling effect of the net long wave radiation served instead, as an additional heat input into the atmosphere-ice-ocean heat balance. The effect of this error was almost negligible in winter when ice is thickest, but could melt as much as 50-100 cm of arctic ice in summer. August monthly mean values of net long wave radiation show that the error resulted in an added average heat flux of 20 watts per square meter over the central Arctic. A summer ice

thickness field is shown in Fig. 1 with the corrected long wave radiation and in Fig. 2 an identical case but with the sign error. This excessive heating was responsible for an average of 50 cm of melted ice in the central Arctic.

Examination of the surface air temperature was performed in a more quantitative manner. PIPS 1986 surface air temperatures were compared to a data set of climatological surface air temperatures used by Walsh et al (1985). Figure 3 shows the monthly mean difference of these surface air temperatures averaged over the entire PIPS grid. Slight deviations from climatology, such as those from February through September are expected. However the extreme cold temperatures of January and the extreme warm temperatures of October through December point to an error in the atmospheric model's heat balance. Results using the 1986 NOGAPS forcing with surface air temperatures replaced by the climatology for October through December showed a basin wide average increase in ice thickness of 30 cm. The cold temperatures in January were responsible for the excessive ice in the Barents Sea.

Excessive atmospheric heating is most destructive in summer. During the summer of 1988, PIPS results showed almost a total "melt down" of ice in the central Arctic. During this summer, the NOGAPS model contained an error which resulted in excessive atmospheric heating. Statistical analysis of the NOGAPS fields showed the surface air temperature between 4-5 degrees too warm. A test simulating a 4 degree warming of the atmosphere using the 1986 data was made. Figure 4 shows the drastic effect of this excessive heating combined with the sign error in the long wave radiation, a situation which also existed in 1988. The combination of these two heat sources, particularly the warm surface air temperatures (compare to Fig. 2), were capable of making the central Arctic nearly ice free by the end of August.

CONCLUSION

The errors discussed in this paper represent extreme situations. However, even small errors in any of the numerous forcing fields needed to drive an ice model may combine to cause serious errors in the ice thickness, ice concentration or ice drift fields. The NOGAPS model discussed in this paper has already been replaced by a spectral model with twice the resolution. These improved global models as well as regional polar atmospheric models are needed if we ever hope to make accurate sea ice forecasts.

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ICE THICKNESS AUGUST 31, 1986

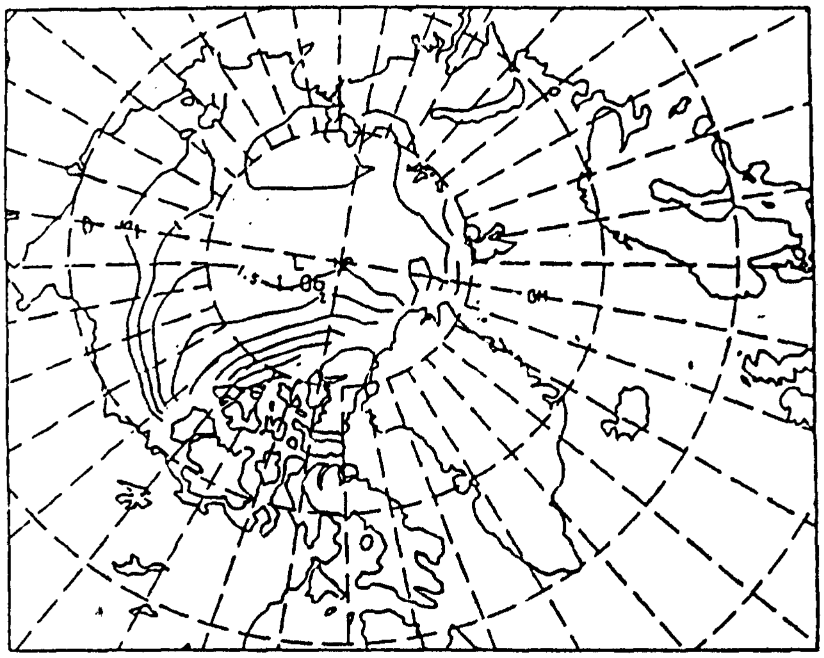

Figure 1. Summer ice thickness for standard case. Contour interval is 0.5 m.

ICE THICKNESS AUGUST 31, 1986

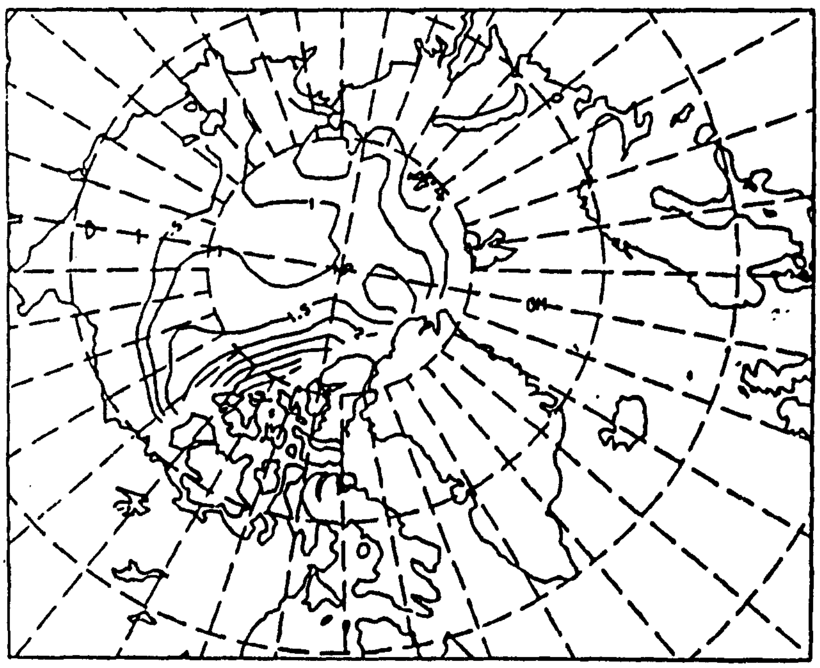

Figure 2. Summer ice thickness for the same case as Fig. 1 but with sign of the net long wave radiation reversed. Contour interval is 0.5 m.

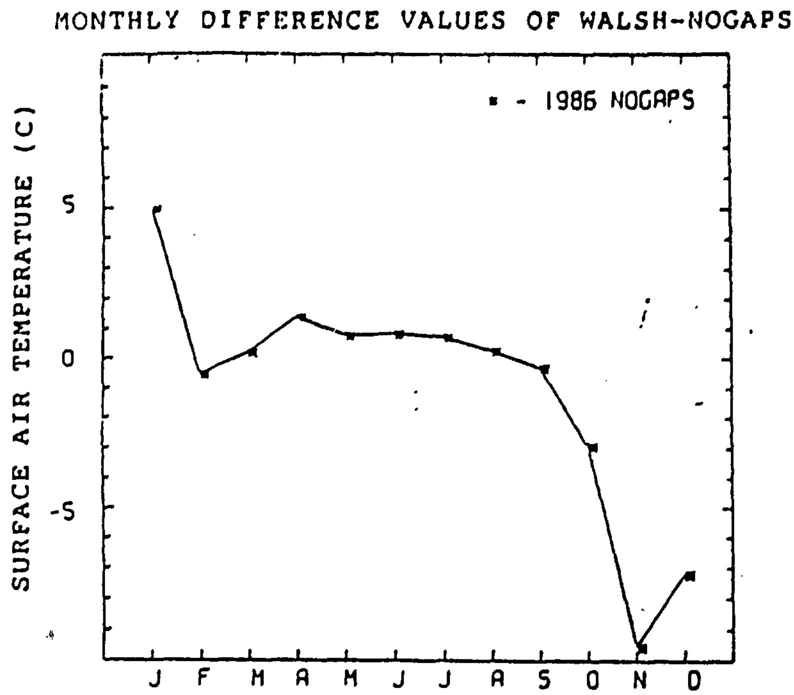

Figure 3. Monthly mean difference between climatological and NOGAPS surface air temperatures averages over the PIPS domain.

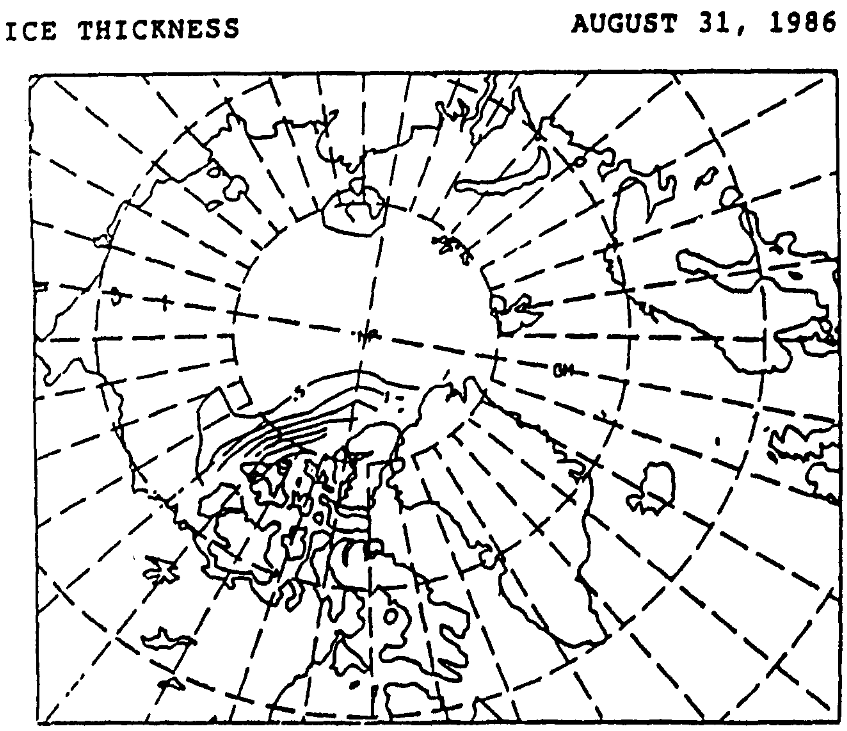

Figure 4. Ice thickness for the same case as Fig. 2 but with 5 degrees added to the surface air temperature. Contour interval is 0.5 m.